VERY LOW FREQUENCY AC HIPOTS

A REVIEW OF VLF TESTING & ANSWERS

TO FREQUENCY ASKED QUESTIONS

HIGH VOLTAGE INC.
VLF HIPOT INSTRUMENTS

VLF-25CM
0-25 kV @ 0.4 uF

VLF-4022CM
0-40 kV @ 5.5 uF

VLF-12011CM
0-120 kV @ 5.5 uF

Models Available

VLF-25CM	0 – 25 kVAC, load rated to 0.4 uF
VLF-4022CM	0 – 40 kVAC, load rated to 5.5 uF
VLF-50CM	0 – 50 kVAC, load rated to 50 uF
VLF-6022CM	0 – 60 kVAC, load rated to 5.5 uF
VLF-65CM	0 – 65 kVAC, load rated to 22 uF
VLF-12011CM	0 - 120 kVAC, load rated to 5.5 uF
VLF-20055CM	0 - 200 kVAC, load rated to 5.5 uF

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This paper is written to answer the many questions concerning VLF AC Hipots and their applications. It is not written to make the argument for VLF AC cable testing versus DC. That case has been made for years, with near unanimous worldwide consensus that DC testing is not only damaging to solid dielectric cable insulation but is also an ineffective means of determining the insulation quality of a cable. Proof enough is the fact that European standards have been in place for years for VLF cable testing and in North America, the IEEE, EPRI, CEA, and others have denounced DC testing for years, with the IEEE having written a new test standard for VLF that is soon to be implemented.

What is VLF?

VLF stands for **V**ery **L**ow **F**requency. VLF is generally considered to be 0.1 Hz and lower.

Many people assign too much mystery to VLF testing. A VLF hipot, and VLF testing, is very simple. It's just an AC hipot but with a lower frequency output. We have all used AC hipots for decades to test various types of equipment. Now they can be used for field testing cable and rotating machinery.

Where is VLF used?

VLF testing is used for any application requiring AC testing of high capacitance loads. The major application is for testing solid dielectric cable (per IEEE400.2), followed by testing large rotating machinery (per IEEE 433-1974), and occasionally for testing large insulators, arrestors, and the like.

Even if a utility doesn't adopt VLF for widespread cable testing, one of the best reasons to use VLF is to check installation quality and accessories, like splices. Many failures are due to damage during installation and/or defective workmanship. At the very least, every newly installed or repaired cable should be VLF tested before re-energizing.

What VLF hipots are available?

High Voltage, Inc. produces VLF hipots from 25 kV up to 200 kV, the widest range in the industry. Load ratings are available from 0.4 uF to 50 uF, representing approximately 4000' to 40 miles of 15 kV cable.

Why 0.1 Hz?

The only way to field test high capacitance loads with AC voltage, like cables and motors/generators, is to use a VLF AC hipot. The lower the frequency, the less current and power needed to test high capacitance loads.

X_c (capacitive reactance) = $1/2\pi fC$. A 10,000' 15 kV cable has approximately 1uF of capacitance. The capacitive reactance at 60 Hz is 2650 ohms. To apply the IEEE recommended 22kV test voltage, it would require a power supply rated for 8.3 amps, or 183kVA. Obviously not practical for field use.

At 0.1 Hz, the capacitive reactance is 1.6 megohms. The same 22kV would draw only 14mA, or only .302kVA, or 600 times less than at 60 Hz. At 0.01 Hz, a cable 6000 times longer can be tested than at 60 Hz.

Is 0.1 Hz still AC?

Yes. The wave shape is sinusoidal and capacitance doesn't change with frequency.

How do you do the test?

The test is very simple. With the cable to be tested isolated, connect the high voltage output lead of the VLF to the conductor and ground the shield. Like any hipot, apply the test voltage for the required duration.

What's the test voltage and for how long?

The IEEE/EPRI/CEA and other world engineering bodies recommended test level for solid dielectric cable is up to three times (3Vo) line to ground voltage for 15 + minutes. For a 15 kV cable, which ordinarily carries from 7.2 to 8 kV line-ground voltage, the test is usually performed at 22 kV. A 25 kV system is tested up to 33 kV and a 69 kV cable system is VLF tested up to 120 kV.

Different VLF units output different waveforms. What's best?

All High Voltage, Inc. VLF units produce a perfect sine wave output. The original German designs, which are still offered, do not produce a sine wave output. They produce a trapezoidal waveform. They often try to claim that it's superior to the sine wave: a very tough argument to make. They don't produce a sine wave VLF. How can any engineer argue with a sine wave output?

Also, for a VLF unit to be used for diagnostic testing, either Tan Delta of Partial Discharge, it must produce a sine wave. The IEEE recognizes the sine wave output as advantageous and mandates it when the VLF unit is used for testing rotating machinery. Stick with a sine wave unit.

Is the VLF test destructive?

VLF hipoting is not destructive to good insulation and does not lead to premature failures like with DC voltage testing. Using VLF does not cause degradation of the insulation. It does cause existing cable defects, like water trees and splice defects, to break through during the test. If a cable can't hold 2 – 3 times normal voltage, it is not a good situation. Cause failure at defect locations during a controlled outage or prior to energizing newly installed or repaired cables, find the fault, make the repair, and be left with a good cable. It is AC voltage; what the cable is designed for and experiences during service. Cable is factory tested with AC voltage at levels higher than the field test voltage.

When people talk of VLF testing being destructive, it is only destructive in that a defective cable, joint, or splice may fail under test, which is the intent of the test. How can any engineer doubt the efficacy and effectiveness of testing a cable designed to carry AC voltage with AC voltage?

But my cable might fail during the test

Precisely. That is the point of VLF testing. It is not a diagnostic test. It is an AC stress test. There are no leakage current readings to take. (DC leakage currents tell little about the cable quality.) A cable either holds the test voltage or fails. If a cable can't hold 2 – 3 times normal voltage, it's not going to last long. You want it to fail during the test, when you are ready to repair or replace it.

Who endorses VLF?

Nearly every engineering body in the world. EPRI, IEEE, CEA (Canadian Electric Association), other country's engineering organizations, nearly every cable manufacturer, and many utilities throughout the world have embraced the effectiveness of VLF testing. German VLF test standards (DIN-VDE Standard 0276-620 & 0276-1001) have existed for many years, the IEEE has written a VLF specific cable testing standard (IEEE 400.2) that will soon be implemented, IEEE400-2001 embraces VLF as a viable alternative to DC testing, and IEEE Standard 433 for VLF testing of rotating machinery has existed for nearly 30 years.

Why hasn't VLF been more widely used?

VLF is not new. The reason it has not been widely used for more than 4-5 years is because only in the last 5 – 10 years has it been determined that DC voltage testing damages solid dielectric cable and is an ineffective means of determining insulation quality. Also, the original and current European designed VLF units were and are large, heavy, expensive, and some do not produce the desired sine wave output.

It was not until High Voltage, Inc. developed the first line of truly portable, inexpensive, and sine wave producing units that it became feasible and economical to VLF test in the field. Hundreds of HVI VLF units have now been shipped worldwide over the last 5 years, with thousands to follow.

What are the alternatives to VLF testing cables?

Not much. DC can no longer be used. It damages cable insulation and tells little about the cable insulation quality. Recognizing the problems associated with DC testing, many utilities have reduced their test voltages from 45 – 50 kVDC to 15 kVDC on 15 kV cable. 15 kVDC is barely above the peak AC stress a cable experiences in service and far below the twice-normal voltage occasionally experienced due to transients. The test is not meaningful.

Some have tried to develop partial discharge detection methods for field-testing cable insulation, with the goal being to determine the insulation quality and location of defects without risking failure during the test. None of the methods employed to date have proven very effective. PD testing may work fine on substation apparatus but it has severe limitations for cable testing. Experience has shown that PD testing lacks reliability, with results often times unrepeatable due to the many variables involved with cable testing: temperature, moisture, number and types of accessories, various cable types spliced together, and operator interpretation. The results are highly interpretive. Also, the equipment and/or the service is very expensive. Many utilities have wasted hundreds of thousands of dollars hiring PD testing services, only to replace good cables and splices while leaving bad cable in the ground to soon fail.

Tan Delta, or dissipation factor, testing (analogous to power factor) is performed, where a VLF unit is used to energize the cable and loss readings are measured. This method works well, so long as there are few splices, joints, etc. along the cable run and there is only one type of cable under test, which is usually not the case since many cable runs are of mixed cable types, all with a different loss factor. This method is easy to perform with minimal training and allows users to grade their cables' level of deterioration. If done properly, it is a non-destructive diagnostic test. High Voltage, Inc. does offer Tan Delta.

The surest way to weed out bad cables and accessories is to just perform a simple AC hipot test, just like we do with vacuum bottles, arrestors, hot sticks, switchgear bus and insulators, etc. Yes the cable may fail under test if it has a severe defect, but that's the point of the test. If a cable can't withstand three times normal voltage for 10 or 15 minutes, it's bound to soon fail. Fail it when convenient, rather than waiting for it to fail on its own, often at the worst possible time.

Summary

A utility faces the choice of how to test their underground cable. Many do nothing and let cables fail, resulting in necessary emergency repairs, adjacent cables damaged, annoyed customers, and loss of consumption revenue: not a good practice. Many have embraced VLF testing to weed out bad cables and accessories with great results. Hundreds more will over the coming years, especially once the IEEE releases its new standard. Many cable failures are due to poor workmanship. The VLF has proven to be a great splice checker. **At the very least, every utility should test their important feeder runs, substation cables, cables to critical customers, and everything newly installed or repaired.**